MERCURIC IODIDE ROOM TEMPERATURE GAMMA-RAY DETECTORS*

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ABSTRACT

High resolution mercuric iodide room temperature gamma-ray detectors have excellent potential as an essential component of space instruments to be used for high energy astrophysics. Mercuric iodide detectors are being developed both as photodetectors used in combination with scintillation crystals to detect gamma-rays, and as direct gamma-ray detectors. These detectors are highly radiation damage resistant. The list of applications includes gamma-ray burst detection, gamma-ray line astronomy, solar flare studies, and elemental analysis.

A. MERCURIC IODIDE PHOTODETECTORS[1]

Mercuric iodide (HgI_2) has been developed to a considerable extent, though not perfected, as a photodetector (PD) used in combination with a scintillation crystal to detect gamma-rays. Because of its large bandgap the material offers room temperature operation with superior electronic signal-to-noise ratio when compared to other semiconductor PDs. In addition, HgI_2 PDs offer significant advantages over the conventionally used photomultiplier tube (PMT). HgI_2 PDs coupled to CsI(Tl) scintillation crystals have yielded energy resolution superior to any other scintillator/photodetector combination.

The characteristics of HgI_2 photocells are as follows:

1. **Size.**

There is a significant overall instrument size reduction afforded by substituting PMTs with HgI_2 PDs. PMTs are inherently large because of the electron optics and the required interdynode spacing. The volume for a 1 inch diameter active area HgI_2 PD is about one twentieth of the volume of a typical PMT with the identical active area. In instruments that might employ many detectors in arrays such as the flies eye array for directional detection, this advantage is multiplied by the number of detectors employed.

Feasibility for deploying large arrays of multiple detectors will be enhanced due to these size and weight advantages.

2. Active area.

Single crystal photocells with active areas ranging from 0.125 inches to 1.5 inches in diameter have been developed and tested. The detector active area is limited only by the size of currently available crystals. Larger active areas can be achieved by using a mosaic of HgI_2 crystals. The technique for fabricating crystal mosaics is in the development stage. HgI_2 PDs can be fabricated in shapes other than the conventional circular geometry to more fully cover the optical interface. A mosaic of approximately three elements will cover an 8 cm diameter scintillator such as the one used in the detector for the KONUS experiments[2].

3. Quantum efficiency.

The quantum efficiency (QE) of HgI_2 PDs is nearly unity in the visible range of the electromagnetic spectrum. PMTs on the other hand have QE's lower than 15% in this part of the spectrum. Because of this the HgI_2 PD is able to collect more of the scintillation light, and it will therefore have better photon statistics. Above 200 KeV, this results in superior energy resolution for the HgI_2 PD based spectrometer versus the PMT based spectrometer. Below 200 KeV however, the QE advantage is compromised by the dominant electronic noise in the preamplifier. This is an area that we are working to improve.

4. Detector Performance.

The spectral performance of the HgI_2 PD based spectrometer is outstanding: A 1 inch diameter HgI_2 PD coupled to a 1 inch diameter by 1 inch thick CsI(Tl) scintillator gave a ^{137}Cs resolution of 5.0% FWHM, and a 1.5 inch diameter PD coupled to a 1.5 inch diameter by 4 inch thick CsI(Tl) scintillator gave a resolution of 5.7% FWHM for the same source energy. For comparison, note that the best ^{137}Cs resolution ever obtained using a PMT based spectrometer was 5.6% FWHM.

5. Detector speed.

Detector risetimes are typically about 1 microsecond. A shaping amplifier time constant of at least four times that value is required to optimize electronic signal-to-noise. For most detectors shaping time constants of between 10 and 30 microseconds are used. This sets the limit on the count rate capability in an optimized HgI_2 PD based spectrometer to about 30 Kcps. This timing scenario also sets limits on the event time discrimination that can be used in gamma-ray burst direction determination.
Gamma-ray burst risetimes have been reported to be in the range 10-1000 ms, with durations in the range of a few tens of milliseconds to several hundreds of seconds.

6. Detector lifetime.

Some earlier PDs exhibited lifetimes of up to 1.5 years. Lifetimes are expected that far surpass this figure for more recently developed samples with improved entrance

electrodes and that employ an encapsulating layer.

7. **Power supply requirements.**

Operating currents range from 30 pA to 1 nA for a bias of 500 volts. The DC stability of the power supply is not critical, and variations of up to ± 10% can be tolerated without affecting the PD gain. This is a significant advantage over PMTs whose DC precision is critical, as the PMT gain is highly sensitive to any variation in the DC level. The complexity of the power supply design for scintillation spectrometer instrumentation can therefore be significantly reduced when HgI_2 PDs replace PMTs.

8. **Areas of current research.**

Emphasis is placed on areas which will improve important aspects of detector performance. These areas are electronic signal-to-noise for improvement in spectral response at the low energy end of the spectrum, techniques for increasing the detector active area in order to improve sensitivity, studies of new materials suitable as entrance electrodes that produce good performance increased longevity PDs.

B. VOLUMETRIC DETECTORS FOR DIRECT DETECTION OF GAMMA-RAYS

Mercuric Iodide is of interest as a solid-state gamma-ray spectrometer because of its large bandgap and high atomic number. These properties allow for room temperature operation and afford high gamma-ray cross section respectively. In addition, the material exhibits a much higher resistance to radiation damage than semiconductor detectors such as HpGe. Radiation damage experiments with HgI_2 detectors exposed to 1.4 GeV protons at an accumulated dose of 10^9 protons/cm^2 (equivalent to one year in space) showed no degradation in spectral response.

The characteristics of HgI_2 gamma-ray detectors are as follows:

1. **Size, efficiency, and spectroscopy considerations.**

In HgI_2, photoelectric absorption dominates other interaction processes to about 400 keV. At higher energies (up to several MeV) Compton scattering dominates. Detectors of thicknesses from 1.0 to 10.0 mm are used for increased detection efficiency and to minimize Compton escape events at high energies. For detectors of 2 to 4 mm thickness energy resolutions in the range 3% to 10% FWHM with peak to valley ratios of about 4.0 for the ^{137}Cs 662 keV photopeak are routinely obtained. In thicker detectors incomplete charge collection (hole trapping) limits the energy resolution. Gamma-ray counters of about 1 cm thickness have resolution limited to >10%.

The mean free path for gamma-rays in the 400 keV to 10 MeV region in HgI_2 is between 1 and 4 cm, so that the intrinsic detection efficiencies are between 33% to 5%. At 662 keV the linear attenuation coefficient in HgI_2 is about 0.58 cm^{-1}. This means that about 13% of the 662 keV gamma-rays are being stopped in a gamma-ray detector with

typical thickness of 2.5 mm. Where more efficiency is required, it is necessary to go to thicker detectors at the expense of energy resolution.

In order to circumvent this trade off between energy resolution and efficiency various schemes have been adopted. An approach being developed is to stack thinner detectors vertically and horizontally to retain optimal charge collection and simultaneously fulfill the volume requirement for high efficiency. In addition, pulse processing methods[3] which compensate for the incomplete hole collection have demonstrated significant improvements in energy resolution for detectors of 1 to 5 mm thickness.

2. Detector lifetime.

Recent advances in material processing at EG&G have allowed yields of 30% to be achieved in producing good quality HgI_2 gamma-ray spectrometers (3% to 11% FWHM at ^{137}Cs) of moderate thickness (2 to 4 mm). In addition, the development of new encapsulation methods have improved the long-term stability of HgI_2 detectors. Most recently, a set of detectors under constant test for the past six months have shown no degradation in spectral response.

SUMMARY

Mercuric Iodide detectors may be used in gamma-ray spectroscopy either directly or as a photodetector in combination with scintillation crystals. Mercuric Iodide photodetectors offer the following advantages over photomultiplier tubes: reduction in size and weight, greater response uniformity, higher quantum efficiency, improved spectral resolution, simplified biasing requirements, low supply currents, and insensitivity to magnetic fields. Mercuric Iodide semiconductor detectors for direct gamma-ray spectroscopy offer room temperature operation with good energy resolution and high efficiency. Both types of HgI_2 detectors are highly resistant to radiation damage.

REFERENCES

[1] Markakis, J.M. *IEEE Trans. Nucl. Sci.*,Vol. NS-35, No. 1, Feb. 1988, 356.

[2] Mazets, E.P. & Golenitski, S.V. *Astrophys. & Space Sci.*, 75 (1981) 47.

[3] Gerrish, V.M. & Beyerle, A.G. *Nucl. Inst. & Meth. Phys. Res.*, A283 (1989) 220.

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